Film Flow along Tunnel Walls

Teamrat A. Ghezzehei and Stefan Finsterle
Contact: Teamrat A. Ghezzehei, 510/486-5688, taghezzehei@lbl.gov

RESEARCH OBJECTIVES

Dripping of liquid water into tunnels or caves affects natural processes (such as formation of speleothems) and is important to engineering applications (such as mining and geologic disposal of nuclear wastes). Current computer models of these processes assume that liquid water drips immediately after entering the tunnel. In contrast, recent field observations showed that film flow and wetting of tunnel walls result in a temporal and spatial lag between liquid emergence and subsequent dripping. The objective of this research is to assess the impact on seepage of film flow along rough tunnel walls and provide a framework for realistic modeling of seepage and evaporation.

APPROACH

In this research, conceptual models are developed by capitalizing on recent advances in our understanding and modeling of (1) unsaturated flow near and around tunnels, (2) characterization of unsaturated flow on rough surfaces, and (3) dripping from pendant rivulets. To provide better insight into these hitherto poorly understood phenomena, the research favors analytical models that use simplified geometries and flow conditions.

ACCOMPLISHMENTS

The conceptual model developed thus far is schematically described in Figure 1. Liquid water enters subsurface tunnels at regions where the near-ceiling pores or fractures are fully saturated. Subsequently, the rough tunnel walls intercept the liquid, and film flow occurs, mediated by the *capillary roughness*, which is generally on the order of one millimeter. Flow along the unsaturated wall is driven by capillary and gravitational gradients, as described by the Buckingham-Darcy law. In the unsaturated portions of the tunnel wall, relatively strong capillary adhesion prevents dripping. Dripping occurs at any location on the ceiling where sufficient positive pressures develop with aerial extent equivalent to the base area of a pendant drop. To facilitate derivation of an analytical solution, we developed a one-dimensional steady-state model for a cylindrical tunnel, as shown in the right panel of Figure 1.

SIGNIFICANCE OF FINDINGS

Typical capillary pressure (ψ) profiles for several tunnel sizes are shown in Figure 1. Generally, the wetness of the crown region increases with tunnel size because of reduced gravitational forces that are insufficient to drive the liquid away. Consequently, larger tunnels are more prone to dripping. The variable wetness of tunnel walls can be used for physically based estimation of evaporation losses into the tunnel air.

RELATED PUBLICATION

Ghezzehei, T.A., and S. Finsterle, Film flow on tunnel walls and its role in decreasing seepage. Vadose Zone Journal, 2003 (submitted).

ACKNOWLEDGMENTS

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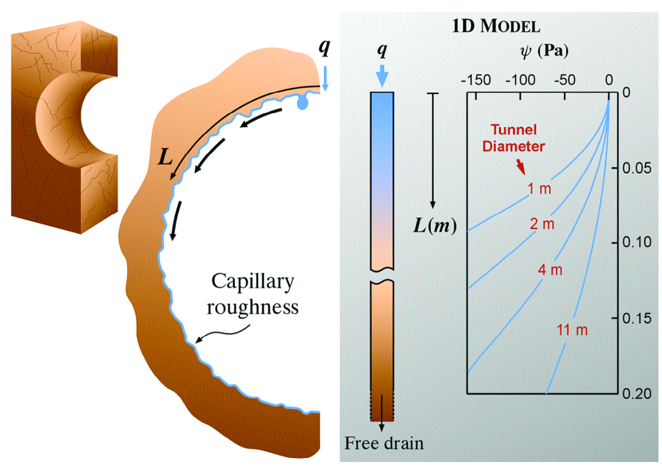

Figure 1. Schematic diagram of film flow along a cylindrical tunnel wall. The cross section depicts liquid entry at the crown and film flow mediated by capillary roughness. The right panel shows the one-dimensional model of film flow along the tunnel wall and typical capillary pressure profiles for several tunnel sizes.